Modeling the Life and Death of Commercial Place Under Recurrent Hazard Future

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Motivation & Context

- Florida's Gulf Coast has experienced recurrent major hurricanes, including **Hurricane Ian in 2022** and the back-to-back landfalls of **Helene and Milton in 2024**, compounding disruptions to coastal infrastructure, local economies, and long-term recovery efforts.
- **Coastal commercial areas** are especially vulnerable to recurrent natural hazards.
- Recurrent disasters and sea-level rise are accelerating the **decline of commercial land**, forcing business closures, relocations, and long-term **vacancies**.
- These disruptions not only affect the **built environment** but also erode the **social and economic infrastructure**, which may trigger cascading effects like reduced access to services, population displacement, and slowed recovery.

Demand for predictive tools that can identify commercial land **vulnerabilities**, simulate future hazard **scenarios**, and inform proactive **adaptation strategies** for economic resilience.

Knowledge Gap

Conventional land use models struggle to capture cumulative consequences of short-term shocks:

- Insensitive to weekly/monthly changes in human activity.
- Treat disasters as one-time events rather than cumulative processes.

Commercial land use change is particularly complex:

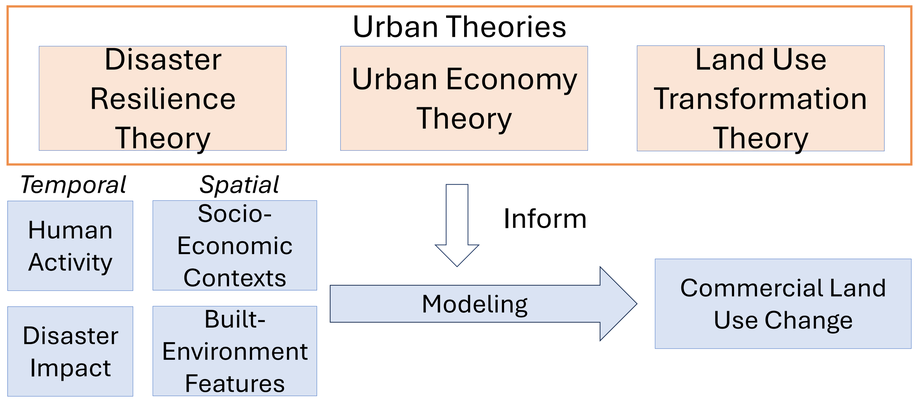
- Highly sensitive to customer demand disruptions following disasters.
- Influenced by competitive and cooperative spillovers among nearby businesses and districts.
- Subject to nonlinear, bi-directional diffusion of both decline and growth across space.

Existing deep learning approaches are rarely tailored to urban theory:

- Temporal modeling lack resilience logic.
- Spatial modeling relied on physical proximity, not functional linkages between business zones.
- Overlooked land use diffusion .

Modeling Challenge

Modeling Challenge	Theoretical Basis	Modeling Innovation
Temporal signals conflate disaster effects with normal variation	Resilience Theory	Time attention mechanism prioritizes post-disaster periods and localizes behavioral shock
Commercial areas interact beyond physical adjacency	Spatial Economic Competition Theory	Multi-relational graph captures non-local, functional competition between business zones
Directional diffusion of commercial change is ignored	Urban Diffusion Theory	Diffusion-aware loss models asymmetric expansion and retreat patterns



Method

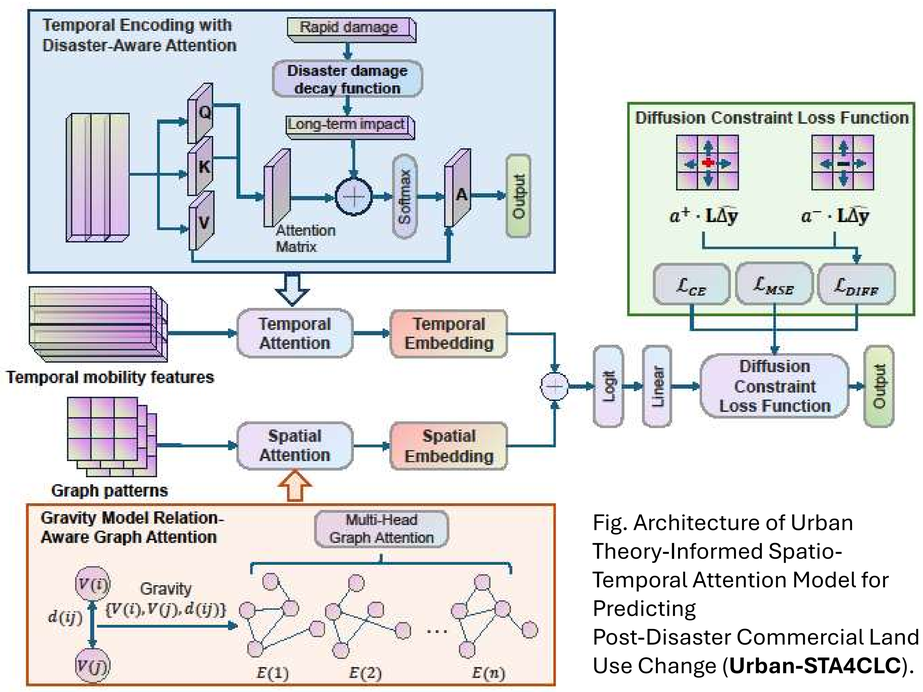
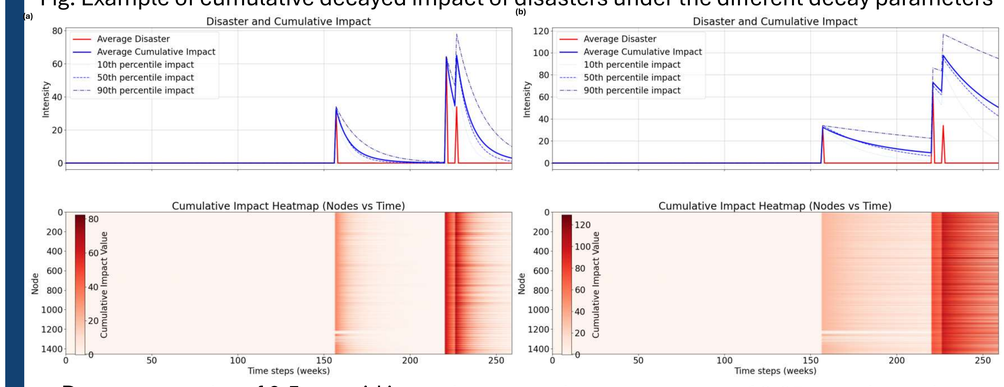


Fig. Architecture of Urban Theory-Informed Spatio-Temporal Attention Model for Predicting Post-Disaster Commercial Land Use Change (**Urban-STA4CLC**).

Fig. Example of cumulative decayed impact of disasters under the different decay parameters



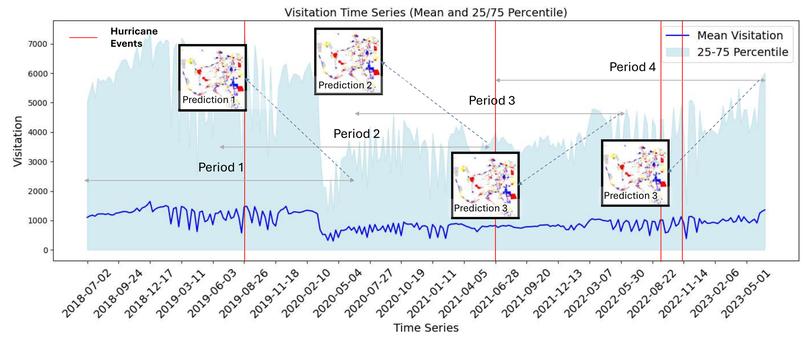
Decay parameter of 0.5, a rapid impact

decay parameter of 0.05, a prolonged impact

Results

Model Calibration:

- Cape Coral Metropolitan area in Florida, U.S., where recurrent hurricanes and challenging economic.
- 260 weeks of data across four time periods with 1,453 census blocks. Each period includes 104 weeks leading up to the predicted year of land use change.



- The model performance achieves an F1 of 0.8763, significantly outperforming none-theory informed baselines and ablation variants.

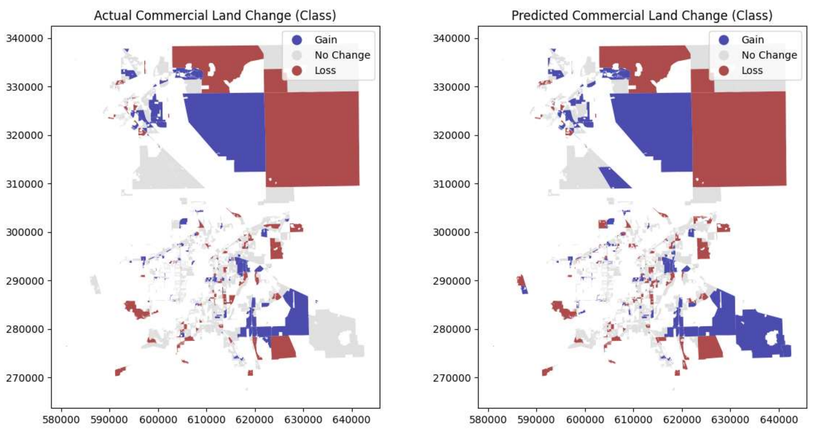
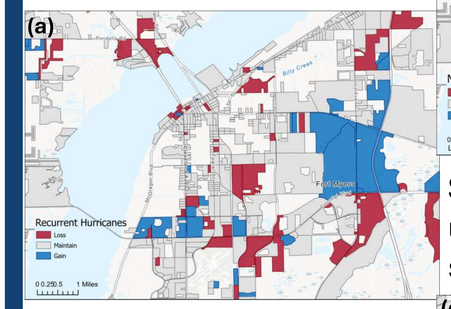
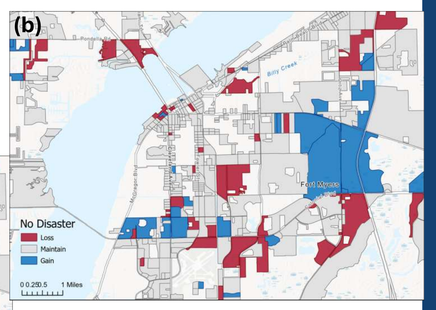


Fig. Predicted and actual land use change in year 2021-2023

Applications:

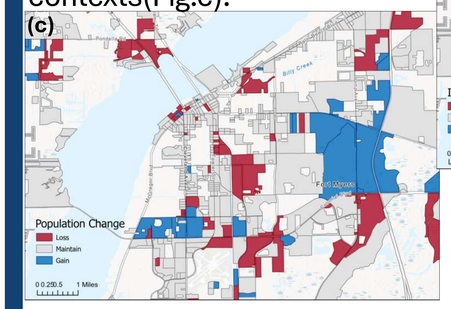
Identifies commercial areas at risk of vacancy after single or multiple disasters (Fig.a).

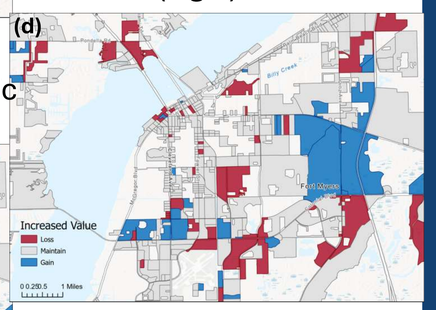




Simulates land use change under varying disaster scenarios (Fig.b).

Supports scenario planning across different socioeconomic contexts(Fig.c).





Evaluates impacts of planning strategies (land use or infrastructure changes, Fig.d).

Provides decision support for resilience planning by helping planners anticipate disruptions, optimize land use, and refine adaptive policies before implementation.